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ABSTRACT

This conference presentation suggests three key ingredients for motivating talented mathematics and science students. The first ingredient is the nature of the content in the courses offered. For instruction to successfully motivate, it should reveal the dynamic nature of mathematics and science, involve challenging materials, synthesize and integrate wide-ranging topics, and reveal the application of course content to life. The second ingredient is the flexibility of the curriculum, which involves accelerating coverage of material and enriching its content. The third ingredient is interaction with intellectual peers through special competitions, pull-out programs, summer programs, etc. In a reaction to the paper, Burton Stuart comments on the teacher's role as the most important factor in educating talented students, notes the advantages of acceleration but the dangers in overplacing students, and examines elementary school teachers' deficiencies in mathematics/science ability and training. Solomon Garfunkel then presents some mathematical problems used with talented students. (JDD)

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MOTIVATING THE MOST CAPABLE YOUTHS IN MATHEMATICS AND SCIENCE

Kevin G. Bartkovich

Introduction

The subject that I have been assigned for this paper is unique in my experience. Professionals often discuss the best ways to educate the most capable youths in mathematics and science, frequently debating the merits of acceleration, enrichment, individualized study, pull-out programs, summer programs, and other strategies for working with academically talented students. The focus of these discussions is generally limited to the product of the system, specially, what skills and understanding the highly talented students possess when they leave the high schools for college. Concern for the motivation of the most capable young students is rare, yet such concern is immeasurably more important than an exclusive interest in the acquired knowledge of the product of our schools.

For example, a team of three high school students from the North Carolina School of Science and Mathematics submitted one of the six winning entries in the National Mathematical Modeling Contest. This team was the only high school team entered; the other teams were from top universities around the nation. What enabled this group of young students to do so well? Clearly they possess brilliance to go with an excellent mathematics education; however, talent and knowledge alone did not enable them to work for nearly four straight days with little sleep to prepare their contest solution. A crucial aspect of their effort was the motivation to pursue excellence and to use their talents to the fullest extent possible.

The emphasis on motivation in the title of this paper implies that we are interested in more than the test scores or amount of advanced standing an individual has achieved. On the one hand, the product encompasses what the student has already achieved; however, interest in the motivation of an individual looks forward to future achievements. Given a certain level of expertise, motivation is a major factor in determining what a young person will accomplish as an adult. Striving to give our brightest young people the best training possible is a worthwhile goal, yet without strong motivation even the best education can yield unsatisfactory results in the long run. Profound implications follow from placing high priority on the motivational value of the curriculum. In this paper, I suggest three key ingredients for motivating talented mathematics and science students.

Content of the Curriculum

The first element critical to motivating talented students is the nature of the content in the courses offered to these individuals. For a course to have positive motivational value, several features must be present in the instructional materials.

A. Mathematics and science instruction must be built around content that reveals the dynamic nature of mathematics and science. Instruction must involve more than memorizing facts, formulas, and problem-solving algorithms. In science class, we can easily picture students tinkering and performing experiments; however, similar instruction in mathematics is difficult to imagine. For example, the law of cooling is a standard application of exponential functions found in

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precalculus mathematics textbooks. The textbook presentation of the law of cooling usually involves a statement of an exponential equation with several unknown parameters, as follows:

> When a cup of hot tea is left in a room to cool, the temperature of the tea is an exponential function of time. As a matter of fact, the temperature T of the tea is given by T = a x eEbt + c, where t represents the number of minutes from the first temperature measurement. The difference between the initial temperature and the temperature of the environment is represented by a, and b and c can be determined. You are given that the tea is originally 120 degree F and the temperature of the room is 70 degrees F. Also, at t = 15 the temperature of the tea is 98 degrees F. At what time will the tea by 77 degrees F?

This problem statement involves five parameters: T, a, b, t, and c. The problem is easily solved by using the values given for T at times t=0 and t=15 to find the values of b and c. The values of the parameters can then be used to find t for T=77. To solve this problem, a student merely uses simple algebraic manipulations, and the student is not required to possess any understanding of the meaning of the numbers or parameters. This presentation never brings the cooling law to life or allows the students to experience the phenomenon. In contrast, a more dynamic approach involves the following problem statement:

> Heat a cup of water to about 125 degrees F. Place the cup in a room and measure the temperature at regular intervals. Record and graph your data. Does the water cool at the same rate throughout the cooling process? Find a function that approximates the cooling phenomenon you have observed. Use your function to predict when the temperature will be 100 degrees F and when it will be within one degree of room temperature. How do your predictions compare with the observed data?

The second presentation of the cooling problem brings the phenomenon to life and enables the student to learn by discovery, in contrast to being given a formula that is an accomplished fact. The analysis of the cooling data is enhanced significantly by the use of computer software that transforms and graphs data. As this problem suggests, the availability of calculators and computers in schools provides teachers with unique opportunities to breathe new life into mathematics and science courses. Computer technology in the classroom has the potential to allow mathematics instruction to occur through experiments and discovery learning.

B. Instructional materials must be intellectually challenging to bright students. Academically talented students should be given open-ended questions and problems presented in unfamiliar contexts. A sure test of the quality of the intellectual challenge offered by instructional materials is whether sustained problems are a regular feature of a course. A sustained problem is one that requires a bright student to give a serious and lengthy effort to reach a solution. The effort may require as little as 15 minutes or as much as many hours spread over several days, but certainly more than the common situation in which a bright student finishes a homework assignment before leaving the class in which it was assigned.

Polya describes a number of ingredients of problem-solving processes in terms of insightful questions that a student must ask. Among these questions are the following:

> What is the unknown? What are the data? What is the condition? . . . Have you seen if before? . . . Do you know a related problem? Could you restate the problem? Could you restate it still differently? . . . If you cannot solve the proposed problem try to solve first some related problem. Could you imagine a more accessible related problem? A more general problem? A more special problem? An analogous problem? Could you solve a part of the problem? Keep only a part of the condition, drop the other part; how far is the unknown then determined, how can it vary? . . . Carrying out your plan of the solution, check each step. Can you see clearly that the step is correct? Can you prove that it is correct? . . . Can you check the result? Can you check the argument? Can you derive the result differently? Can you see it at a glance? Can you use the result, or the method, for some other problem?

Problems that are challenging and require a sustained effort will lead talented students to ask many of Polya's questions in one form or another. Students are shortchanged if instructional materials are not sufficiently challenging to give them problem-solving experiences at the depth that Polya suggests.

C. Instructional materials must synthesize and integrate topics from a wide range of knowledge. Talented students should see relationships between topics from many parts of a course, and not just the connection between today's topic and what was covered yesterday.

D. Instructional materials should reveal to students the importance of the specific content of a course. In other words, the frequently asked question, "What is this used for?" should receive appropriate attention. This question generally has two classes of answers--how a topic relates to the discipline in which the course is taught, and applications of a topic to other disciplines. As an example, matrices are a fixture of high school precalculus courses. Matrices have many important mathematical properties upon which more advanced mathematical concepts are based. In addition, matrix models are widely used in the sciences, such as the Leslie model of growth in population biology. Talented students should see both aspects of the usefulness of matrices in precalculus mathematics courses. Most textbooks, however, present matrices only in the context of solving systems of linear equations--a skill that most students perform quite well without using matrices.

Unfortunately, the standard materials developed for typical students do not have the ingredients necessary to be dynamic and interesting for talented youths. In fact, many textbooks are not interesting even for average students. Dynamic content, intellectual challenge, integration of topics throughout a course, and applications from within a discipline and to other disciplines are appropriate standards for instructional materials for all students regardless of ability. A lack of these characteristics in the materials for average students is cause enough for alarm; however, the shortcomings of curricular materials are even more glaring when these materials are used with the most capable students. Even the best

textbooks are written for a broad population so that a large audience is available for textbook publishers. These materials are not appropriate for the brightest students since they do not require the talented students to fully use their intellectual capabilities. Rarely do the problems posed in widely used textbooks require a bright individual to struggle for a solution or to reflect upon the knowledge inherent in the solution of a problem. Concepts often are not interrelated throughout a textbook or with concepts from other disciplines. Typically what is covered in one chapter is not linked with earlier chapters, nor is it used again in later chapters. Motivation for learning a particular topic is not provided from within a discipline, and applications from other disciplines are rarely mentioned.

The weaknesses of the mathematics and science curricula for all students has received much attention in recent years, particularly in comparative international studies. Efforts are underway to address the weaknesses mentioned above; furthermore, there is growing awareness that school instruction in mathematics and science has not kept pace with revolutionary change in technology. For example, traditional high school mathematics involves many symbolic manipulations and numerical calculations easily performed by computers and hand-held calculators. In addition, high school mathematics is being examined not just as preparation for calculus, but as preparation and motivation for a wide range of college mathematics. However, even if materials are developed that incorporate recent developments in mathematics and science, that are intellectually challenging for most students, that integrate concepts over the long-term, and contain numerous applications, these materials will still require adaptation before they are appropriate for use with the most talented students.

The nature of the adaptation of instructional materials for use with talented students can take one of several forms. Suppose a mathematics program is to be designed for a brilliant eighth grade student who is prepared to begin Algebra I. Among the many possible programs, three options are:

1. Get to calculus as quickly as possible, covering only the precalculus topics directly used in calculus;

2. Progress through the precalculus courses at the typical rate of one course each year, while doing "enrichment math" such as context problems in addition to the regular course work;

3. Use instructional materials rich in challenging and open-ended problems, applications, and investigations, and thus prepare the student for a wide range of college mathematics courses, including calculus.

The first scenario has the appearance of covering the most material in the shortest time, but perhaps at the cost of giving students a static view of mathematics as a set of facts, formulas, and algorithms to be memorized. The second scenario has the advantage of maintaining the status quo, but at the risk of turning off an individual with the relatively slow pace. The third scenario is certainly the most difficult to implement, yet it is also the richest in terms of what a student will gain.

The choice of instruction content from many alternatives for the brightest students depends largely on priorities. What is really important for young students? Is it knowledge alone or knowing how to learn and a love of learning? Talented students clearly can master the same material offered to average students at a much faster pace, yet is accelerating bright students through the standard curriculum all that we want to accomplish? If so, then the goals of providing integration, diverse applications, intellectual challenge through problem solving and dynamic material will go largely unmet with talented youths. They may accumulate much knowledge at a rapid pace, yet they will fail to appreciate the dynamic nature of knowledge, nor will they be challenged to develop fully their intellectual capabilities.

Teaching for tests such as the Scholastic Aptitude Testing or an Advanced Placement (AP) examination can be a major culprit in a lack of motivational qualities in instruction. Teaching an AP course can be a positive motivator if the teacher uses the AP syllabus as a guide for developing course content. On the other hand, the test can become the exclusive focus of the teacher and the students, causing a course to deteriorate into memorization of acts solely for the sake of taking an exam. I often hear teachers complain about talented students who are "over-advanced" because they are great test-takers. The implication of the complaints is that these students are able to advance beyond their level of understanding and mastery by virtue of being excellent on standardized tests. I suggest that the problem is not a lack of knowledge, but of motivation. By focusing exclusively on tests and memorization of the required facts, talented students are able to advance beyond their level of motivation. As a result, when they do encounter difficult material, they may not have the motivation necessary to strive to overcome their particular hurdles.

No matter what subject matter is covered with talented youth, the teacher is critically important. In addition to the characteristics common to all good teaching, several aspects of teaching bright students are of special importance. The teacher must have not only an excellent grasp of the course material being taught, but also firm knowledge of more advanced content. The advanced knowledge is necessary for a teacher to be able to cope with the complex questions often posed by talented students. No matter how well-trained or knowledgeable, a teacher must be willing to admit lack of knowledge whenever appropriate. Coupled with the willingness to admit ignorance, however, must be the desire to learn and indeed to be a role model in learning new material. Above all, a teacher of talented students must be flexible, thus creating an atmosphere for open-ended investigations and discussions.

Flexibility of the Curriculum

In addition to dynamic, interesting content, the second essential element in motivating talented students in mathematics and science is the freedom to cover material at a rate consistent with an individuals capabilities. This includes the freedom to move through courses at an accelerated pace, as well as the freedom to investigate a particular concept or phenomenon in greater depth than usual.

Accelerated coverage of material must be balanced with enrichment of content. Bright students should be challenged with more than just moving at a

fast pace through courses designed for average students. They require expanded and deeper instructional content if they are to be challenged to utilize fully their intellectual capabilities.

Acceleration through content areas may eventually lead an individual to advance beyond agemates in grade standing. Grade-skipping is a concern to many parents and educators because of potential social adjustment problems. Remaining with age peers often receives undue emphasis even through research does not reveal adjustment problems due to acceleration. Furthermore, for many young students, no perfect solution exists in attempts to strike a balance between intellectual challenges and social adjustment. For each individual, decisions about grade-skipping should weigh the cost of boredom and lack of stimulation with the potential for social adjustment problems.

A problem that may result form acceleration through a school curriculum is a lack of advanced courses at the upper end of the grade range in a school. For example, middle schools rarely offer any mathematics more advanced than Algebra I in seventh grade will be in a bind in eighth-grade mathematics. In high school, a student who finishes a year of basic physics may be fortunate enough to be offered AP Physics, although such schools are rare nationwide. The likely scenario for a student interested and talented in physics is that an AP course is probably not available, and certainly anything beyond the AP level (introductory undergraduate physics) is exceedingly rare except in special schools for the gifted. The lack of advanced course offerings at many schools stems from the small pool of students who would potentially take these courses. This will continue to be a problem for isolated brilliant students, especially in schools with the least resources such as in many rural and urban areas. Even the option of independent study for isolated students may be problematic because of the amount of teacher preparation required for independent work.

Limits on courses in the upper grades of a school may hold students back from accelerating through material because of the eventual vacuum they will encounter. A frequently proposed solution to the problem is to enrich the courses taken by bright students and thus allow them to be challenged without accelerating through courses. This approach sounds great in theory, but in practice several problems crop up. First, enrichment places a tremendous burden on the teacher. If an entire class is taught with greater depth and breadth than usual, then an excellent teacher will do quite well. A class with only a subset of brilliant students, however, is much more demanding since the teacher is effectively required to teach two courses at the same time in one classroom.

Even in the best circumstances, enrichment strains the background of a teacher. For enrichment to be effective, teachers must receive support for their own learning; otherwise, they will not be able to provide dynamic and currently relevant content for the most capable students. The strain on the knowledge of elementary school teachers is especially acute due to the sparse pre-service training they receive in science and mathematics. The preparation of secondary school teachers may be better, although the number of science teachers teaching outside their specialty is astounding.

Just as acceleration is most appropriate if courses are enriched, so enrichment cannot be implemented without regard for acceleration. Courses that include genuinely enriching content, and not just intellectual exercises designed to keep students in place in a lock-step educational system, necessarily involve acceleration in the sense that students are covering material earlier than they normally would. For example, a teacher might enrich an Algebra I course by drawing from topics in Algebra Ii. On the other hand, if Algebra I is enriched by introducing topics from outside the standard sequence of high school math courses, then the teacher will need to do the extra work of learning the new topics--not an easy task for many teachers considering their usual work load. The problem of teacher preparation in enrichment courses is identical to the problem of teacher preparation associated with an accelerated curriculum.

Interaction with Intellectual Peers

The third essential element in motivating talented students is providing opportunities for them to interact with their intellectual peers. Contact with intellectual peers is crucial in meeting intellectual and social needs. the academic challenge provided by other bright youths is a strong motivator for talented students. A bright student in a class with similarly talented students will have the opportunity to learn more and to learn faster, and in more depth due to the high quality of the class discussions. In addition, a class with intellectual peers often provides brilliant students with their first experience of not being the very best, which can motivate them to achieve greater excellence.

The significance of the social interaction of bright youth is at least as great as the significance of academic challenges. Talented individuals can go to school for a long time without meeting students who have the similar interests. For these young people, forming friendships with others who have similar interests is like a breath of fresh air. For perhaps the first time in their lives, they find that they do not need to hide their talent or their interests. The support and challenge that these students offer each other can often make the difference in motivating an individual to take risks in an academic career and beyond.

Highly capable students can meet intellectual peers through special system-wide or region-wide programs that pull them out of school, through summer programs, through math and science teams, through math and science competitions, and through special schools such as magnet schools or state-wide schools for the academically gifted. In my experience with such programs, students of like interests and talent are drawn to each other at every level of selectivity. For example, on a school math team, participants interact with other students who enjoy mathematics and are the best mathematics students in the school. At a higher level, members of the North Carolina state team that competes in the American Regions Math League contest in June of each year develop friendships with the best high school mathematics students in the state. At the highest level, individuals who are invited to the U.S. Math Olympiad Team training session for four weeks in the summer meet the most gifted young mathematics students in the nation. At each of these levels, I have observed the development of networks of close friendships among the participants. At residential programs such as the TIP Summer Program and the North Carolina School of Science and Mathematics, the ties that develop between students are so strong that the growth of the young

people outside of the classroom may be more important than the growth that occurs within the classroom.

Recommendation

Motivating the most capable young people in mathematics and science requires implementation of strategies that involve intellectually challenging content, that provide freedom for acceleration and enrichment, and that foster interaction among intellectual peers. Lack of appropriate materials is a serious hindrance to providing challenging content; therefore, the teacher is crucial to success in any classroom. Their job is already quite demanding without trying to offer special encouragement and opportunities to the brightest students; furthermore, the informal, investigative atmosphere that is ideal for talented students is often threatening to teachers. Many teachers already do an excellent job with the best students; however, may others need support and assistance in providing for the academically talented. The best teachers are easily identified by examining the Presidential Award winners, participants in the Woodrow Wilson Institutes on high school mathematics, and the sponsors of excellent math teams in competitions such as the North Carolina Math League, the American Regions Math League, and the Mathcounts competitions.

The development of a network of excellent teachers of the academically talented can be fostered through state-wide conferences and professional teacher associations. We presently have an abundance of consultants and coordinators concerned with programs for the gifted and talented students; however, most of these GT specialists are not experts in mathematics and science. Their expertise is more broad-based and administrative, which may be fine for the primary grades; however, in secondary schools, major input is required from the content experts in the classrooms. The best teachers need to be brought into partnership with the GT specialists so that excellent classroom instruction can be combined with appropriate administrative structures.

The implications of a balance between acceleration and enrichment require flexibility and the freedom to design the best program for each individual who is talented in mathematics and science. For isolated students, independent study is often proposed as a means of providing appropriately challenging instruction. whenever possible, however, these students deserve the benefits of being in classes with other individuals of similar capabilities. when the resources of a particular school are exhausted, options outside the school should be investigated, such as college courses and mentorships at businesses and research laboratories. Individuals who are given these options will also then have the chance to meet other young people of similar interests. Classes for talented students, special schools, summer programs, and math and science competitions allow friendships to be formed that provide strong motivation for the most capable young people. For brilliant youths to participate in these special programs, however, requires that teachers and principals be willing sometimes to give up their best students to another program for the overall good of the individual student.

If the above recommendations are implemented, what difference will this make in the long run? Working from within the educational system is often frustrating. The problems that need to be addressed relative to the most capable students are

part of larger problems with the entire range of students. Programs that have been developed outside of the public education system may be great for bright students, but what happens to students during the rest of the year when they are not at a three-week summer program? These are complicated issues, yet significant progress can be made by bringing together the best of both worlds--the best teachers in the schools and the best programs from outside the public schools. If the specialists on gifted and talented education could then support teachers by providing the time and resources for teachers to be learners, then we will find our schools doing what is appropriate for the most capable youths in mathematics and science.

We need to empower teachers to be able to teach mathematics and science as dynamic, challenging subjects. New curriculum materials alone will not succeed in improving teaching--such a strategy would repeat the mistakes of the curriculum reform movements of the 1960s. We must enable teachers to create excitement and discovery in the classroom. This need is the same for all teachers, yet where will it begin? Starting with the best teachers of the brightest students is one strategy. If these teachers then work with other teachers and students, then they can stimulate improvement in the education of all children.

Returning to the title of this paper, motivating the most capable youths in mathematics and science is frequently neglected because of undue concern over what is learned. The actual content of the curriculum must keep doors open to future opportunities; however, much room for diversity exists beyond the core of knowledge that should be imparted to the brightest students. These individuals require challenging and interesting material, flexibility in designing academic programs, and frequent interaction with intellectual peers. Challenge, flexibility, and peer interaction are essential characteristics of a productive environment for professional scholars. Is that not the atmosphere that we should offer our bright students? In any strategy for nurturing talented young people, the most important aim should be to produce life-long, independent scholars. In a nutshell, encouraging and motivating young students to become scholars is the business toward which we should concentrate our efforts.

Discussant Reaction: Motivating the Most Capable Youths in Mathematics and Science

Burton Stuart

Before I start I'd like to just give you a little bit of background information about myself so you'll know my perspective. I'm presently teaching at Chapel Hill High School. My background includes teaching in Denver, Colorado, in Charlotte, North Carolina, at Elon College, and now at Chapel Hill High in North Carolina for the past 15 years. I've taught in junior high, senior high, and college, so I feel like I know where students have been and where they're going. This, to me, is a good balance.

I enjoy teaching junior high kids. I feel as if I'm really needed. You can make an impact on those kids--if you can stand them. In the college area, I enjoyed the subject matter considerably, but really, you don't have much impact on the students, I don't believe.

I enjoy teaching. I teach all levels from geometry for repeaters, who have failed at one time, on up to Advanced Placement calculus. What really excites me is working with the Math Club. I started out eight years ago with seven students who would sometimes show up, and now we have about seventy people that call themselves Math Club members. A typical meeting numbers thirty to forty. We have won some national and state awards in math competition, but that's not what I enjoy the most. I get excited by going to a math contest and seeing the kids arguing answers and talking together. In the Math Club it's more a social occasion than it is learning. They do a lot of learning there; but we have refreshments, and they just enjoy associating with each other. It's something that I'm very excited about.

I'd like to make one little comment before I go to my prepared comment and that is, some of the examples that Dr. Bartkovitch was showing are from some very excellent work. I noticed them from a workshop that I did last summer. The School of Science and Math (NCSSM) people did this with the help of the Carnegie Foundation grant. They have prepared some excellent materials in what I call applied mathematics. We've already incorporated some of them into our own courses at Chapel Hill High, and we're talking about coming up with an applied mathematics course in place of calculus, or in addition to calculus, that will give students more choice.

I do want to give one word of caution to the NCSSM and the others of you who are leaders here. Sometimes I get the feeling that I came in on the opposite side of the room. When I first started teaching the big thing was theory. To prove everything from very simple mathematics on up. I get the feeling now--incidentally, I didn't like that when it came, and I have a lot of it in my teaching now--I feel like we've gone the opposite direction, and applied mathematics is the end word. I'm not ready to go whole hog that way, but I will say there are a lot of things I like about it. What I'm trying to do is stay in the middle, and take the best of both worlds.

Let me agree and emphasize that the teacher is indeed the most important factor in educating brilliant students. All of us can reach back in our background and remember that inspiring teacher who made us think and made us want to know

more about the course. Dr. Bartkovitch has well indicated the preparation and communication abilities that students of such caliber should have. The sad fact, however, is that there are far too few such teachers in schools today, and indications are that, unless drastic changes are made, there will be even fewer in years to come.

There are many obstacles to encouraging talented people toward teaching. Look at the conditions such a person must face. The first, of course, is salary. One of my closet personal friends, a beginning teacher a couple of years ago, left teaching. He had a lot of potential. But he got married, had a child, and his wife wanted to stay home, but he couldn't afford that. After two years he was not yet making $20,000, so he left.

In a typical public school, a secondary teacher teaches five or six classes a day, with nearly 150 students. Sandwiched between meeting these classes is lunch duty, hall duty, bus duty, paper grading, and administrative duties. There is hardly any time to think, much less prepare an exciting class. The teacher is powerless to do anything about these conditions. Decisions are handed down from administrators, with little or no input. More often than not these decisions indicate very little understanding of the needs of teachers of gifted students.

I almost didn't last through my first year. I was teaching an eighth grade class in Denver, Colorado. One of my assignments was a study hall. The study hall consisted of one hundred eighth graders in the lunchroom supervised by two teachers. Unfortunately, the teacher that was with me was absent. Then, they almost drove me out; it was a horrible experience. But that would not have happened if teachers had been in control. The students knew better than to behave like that. I've been asked if I recommend that my best students go into teaching, and I answer regretfully that I do not, even though I have reached a position myself in which I am happy teaching. I believe such positions are not the norm. I have witnessed far too many promising teachers leave because of salary and unbearable conditions.

I would like to say a few words about acceleration versus enrichment. Acceleration is like so many things. It has worked well and it has been disastrous. In Chapel Hill our accelerated program in math for most gifted students begins with Pre-Algebra in the seventh grade and ends with AP calculus in the twelfth grade. But we are seeing more and more students accelerated beyond that, finishing AP calculus as juniors or below.

This works well for some students as they take the next course at the university and do quite well, often going on to math or science careers. In fact, the students who have gone to TIP have, without exception, done very well in their accelerated programs. However, in my opinion, the worst thing that can happen to a student in math is to be overplaced. This is a very personal thing for me because when I first went to college I was considered a good student, and they had me skip two courses of mathematics. And as I say to my students, you're not going to believe this, but I almost didn't like math. I did recover, but some people do not. I find that this is happening more and more, particularly with the students taking the AP calculus as juniors. Several of them in the last few years

have struggled and then have not taken any math as seniors, and as little as possible in college.

I would like to give you two scenarios right here. One is Danny Cory, who has already been mentioned. I think he is a good example that acceleration is appropriate for many kids. In my experience with TIP, I have found that there are many administrative units that will not give students credit for the courses they complete at TIP. Students go back to school and go through the same thing over again. I find that appalling. Well, our system, at least, has made it possible for a person like Danny Cory to move up and advance as far as he can. That's a success story. On the other hand, I can think of another student who took Honors Pre-Calculus as a sophomore. He struggled and did end up improving and making a B. But it was very hard and it wasn't really pleasant for him because he had been used to making A's without any work whatsoever. Well, the student's not taking any math at all right now as a senior, and that upsets me. He should have been one year behind and doing extremely well.

I'm not sure how many students have struggled in math courses before I see them. Our success ratio with these students is high, but I'm troubled that there are many students with high ability that are turned off from math. I believe that the trouble begins with identifying students to accelerate possibly as early as the sixth grade. Often students who are well behaved and do well in arithmetic are identified as being mathematically gifted, which is often not the case. I see identifying truly gifted students as a major problem.

A third problem I see is elementary education. Again, I am speaking in the area of mathematics since my observations have been in this area. More and more has been written about the importance of early education. Incidentally, I had my own laboratory for early education with my own children. I had all sorts of theories that I wanted to try out. Many of them worked. But one thing was that at a very early age, before they could even walk, I read to them, and they are avid readers today, and I'm sure early exposure had a great impact. Another thing, developing leadership qualities: I was interested in developing these qualities in them at a very early age, so one thing that I came up with was during walks across the street. There was a beautiful place where we could walk back in the woods and all over places. So what I would do--there were two of them--is have us all take turns leading. One day my daughter would lead, one day my son would lead, and one day I would. And they were always involved in decisions. When we went out to eat, one day one child would choose where we ate. All four of us would have a choice at different days. They were part of whatever happened to the family. They are now in college, so I can give you a partial report. Indeed it worked. They are very independent thinkers and they do not do things just because everybody else does them, which I think is important in this drug-infested society. This is not a problem that we've had. On the other hand, if I had it to do over again, I think I would teach patience somewhere along the line--my son in particular. I taught him how to play bridge, and then he went and read everything he could read about bridge, and now he's teaching me. Guess what happens when I make a mistake: there is no pity shown to his father.

In this country, the vast majority of elementary teachers are deficient in mathematics and science ability and training. I have witnessed this problem first

hand by teaching a mathematics course for elementary teachers several years ago, and I was shocked by the low ability and interest level I observed there. I can imagine the impact these teachers are having on their students at this very minute. For the gifted students the first seven years of school in mathematics, kindergarten through sixth grade, are wasted. The material could be learned by these students in far less time. No wonder students in America are learning algebra when students of the same age in other countries are learning calculus. To tell the truth, this is the problem that depresses me the most. Because I see it as very difficult, if not impossible, to break the chain of a poor mathematics student becoming a poor mathematics teacher, leading to more poor elementary students.

Finally, I would like to emphasize the importance of the home. It is well documented how Japanese mothers are intimately involved in the education of their children. I was also interested in reading the profiles of this year's Westinghouse Science Talent winners, all of whom indicated they were encouraged and supported by their parents. The support indicated by these students is not just an occasional pat on the back, but the total involvement of the parents in teaching and learning. You don't see this level of involvement very often in American families. I hope that with the reports, the movements going on now, and meetings such as this one, that there will be a movement to improve the conditions I've talked about. But right now, all is not well in the education community.

Discussant Reaction: Motivating the Most Capable Youth In Mathematics and Science

Solomon A. Garfunkel

I've never been a respondent before, and this is sort of fun. What I do for a living is worry about how to teach, how to show people that mathematics is interesting, that it is fun. I do that for all levels of students and teachers, and I wrote in my little notepad--I don't prepare things--I wrote, "fun, real, teachers, too." But what is so much fun is that the example that Dr. Bartkovitch raised about Newton's law of cooking is one of my absolutely favorite examples. But, I don't do it the same way. I say, "Okay, the coroner walks into a room, and finds the body at 92 degrees, so how long has the body been dead?" Let's assume the room temperature didn't change at the time. It's the same exact problem, of course, as Newton's law of cooling. But what happens is this: First of all you get the kids to find out ho coroner's really work. the coroners have a chart. But Newton's law of cooling is the exponential function and the problem is the constant. And what's exciting here is that the constant has nothing to do with the body weight; it depends on the surface area. What coroners actually do is measure height, weight, girth and they've got a little table that tells them the surface area, and then they plug that into Newton's law of cooling and they get an answer that allows them to say the body has been dead for about two to three hours. The question is, "What is the surface area?" And the kids start to figure out the surface area. That is a very hard, an incredibly difficult, problem, and extremely real.

I've got an old English textbook which has several methods. One method is the painting method. You paint the body and you try to measure how much paint is used. There's also the skinning method. And this English text from 1850 says, "This method is not recommend because the skin shrinks when it leaves the body."

The point is you can actually play with the problem. There's lots of physics and other things you could write into it. Let the kids do it and they can get closer or further away from the solution. It's presumably a legitimate problem; and they've seen enough television to know that its a moderately real problem. And they can really work on problems like that. I think that's the point. It's real, it's fun, it's exciting, and totally open-ended, because you can get better and better methods for doing it. It's intellectually challenging and also synthesizes information from all sorts of fields. You have to bring in a little physics, there's some biology, there's all sorts of things that you can look at. Questions about what it's used for don't come up at all. They know right away what it's used for.

If you can look for these kinds of applications, you can find them. In fact, it's silly to call them applications; it's just mathematics. They are just coming in one form or another. Dr. Bartkovitch used a growth example. The growth example I use is one on legislative turnover, bureaucrats and bureaucracies. It turns out if you look at survival rates for bureaucracies in governments and all bureaucrats, they are essentially exponential survival rates, totally independent of whatever the rules are that set them up. So, for example, while it was part of the United States Constitution that Congressmen would serve two-year terms, and Senators would serve six-year terms, if you look at how long an individual senator or congressman stays in office, its exactly the same. The same is true for the

Soviet Union, the Indian Parliament, the U.S. Congress, and the Senate. It doesn't make any difference.

The truth is, I think that what motivates people--students and teachers, and I'm not sure I even want to make the distinction here--is that these problems are intrinsically interesting. Dr. Bartkovitch took me to NCSSM to teach a class which I greatly appreciated. It was lovely to see all the fire behind the eyes. I was talking about sex, drugs and rock-n-roll, that's what kids talk about--and most adults I know, too. I did the randomized response technique with them, which is an example of how do you find out how many people in the population have a certain trait that they are likely to lie about. How many people are gay, how many people take heroin, how many people have taken the AIDS test? Whatever it is, we actually have to ask someone a question knowing that they will lie in response. How do you get good information about that? Read the paper, it says 16.2% of the people in this inner-city neighborhood are heroin addicts. Do you think they all responded "yes"? It's basically a probablistic model. I throw out a deck of cards, and you pick a card out of the deck. If its black you say, you answer the question. And if it's a diamond you say automatically yes, and if it's a heart you say automatically no. As long as I know what percentage of the deck is diamonds, hearts, and black cards I can figure out what percentage of the class, within certain fudge factor, have to answer 'yes' to the right question. It's an elementary probability model using a little conditional probability.

The mathematics that was invented to do this is several hundred years old, more or less. The method was used in 1976 for the first time. Up until then they'd take the numbers and they'd fudge them. Or they'd have some funny, finaglish concept that they multiply two by to get the right answer. They are relatively new problems. That's the kind of thing I'd like to see talented kids be able to do. I think if you can do that on a consistent basis--and the problems are there, and the mathematics are being used that way--I think you can excite and motivate people, and get teachers interested. It's a lot more fun to teach this way, than to teach other ways. The problems are open-ended and you can keep following down the road.

Dr. Bartkovitch talked about the MCM, The Mathematical Modeling Contest that we, COMAC, actually administers. I'll tell you why those kids who won that contest won--because they took the extra step. The problem, by the way, was a drug-running problem. People are people, you know what they are interested in. The problem is stated that there are two sides, with the side in the helicopter trying to overtake the boat. The boat is located directionally; the helicopter takes off to intercept the boat. The helicopter travels three times the speed of the boat, but when the helicopter is within 500 feet, the boat hears it, and can now take evasive action. Question: what is the optimal search pattern for the helicopter? How long would it take to find the boat within a 95% confidence interval-because it's clearly a probablistic and statistical problem. The Coast Guard Academy submitted a paper on the problem. They've got practical experience on the street in this, they do if for a living. At any rate, the point was that people apply these methods, which are very sophisticated, by the way, involving a lot of very heavy mathematics. But the kids took it the extra step. A lot of people came up with a similar answer, but the kids actually considered what would happen if the weight of the boat was so at a certain level, what if the

driver did something, and so on. They actually looked at the model one step further and, interestingly enough, most of the college teams stopped. They got a pattern, probability, and numbers, so they stopped. These high school kids just kept going. We asked them to look at the model, at how to expand it, from the captain of the boat getting drunk to the waves being too high a wave coming in or a heavy wing; they just kept looking at different problems that could have cropped up with the model and different ways of looking at it. If that isn't the best possible thing to have happen I don't know what is, and I'm sure that's why the paper was chosen.

When we talk about materials like that, of course, the point is that texts don't do the job. Textbooks are reactive and they take time to change. That, of course, is why we are in this business, because we produce modular materials at high school and college levels for teachers and students, of the kinds of examples we just talked about--to give people the option. One of the things you can do with the modular approach, and I'm not trying to sell anything here, take the 10 or 20 pages necessary to explain the application field that's not the mathematical field. No textbook will ever do that, which is the real problem. No textbook is going to expend time teaching the biology, chemistry, or social science of a problem, because then the books would get bigger and bigger. That's why we produce various modular materials. First of all they are flexible, pick and choose; and second of all because you can actually put in one place all the kinds of outside material you need while you learn the mathematics.

The modular concept makes the world a little more flexible and allows for something else Dr. Bartkovitch was talking about. Yes, students should move at their own pace, accelerate depth versus speed. Freedom of pacing, interaction, it's so obviously right, it's hard not to talk about. We could have done an individual contest, with kids sitting in a room like the Putnam does, for six hours behind a locked door--that's the Putnam approach. But we said basically, that's not the way people do problems in the world, in any mathematics, nobody works that way. That's the reason I think we decided to do the modeling competition the way we did: We decided students would work as teams with resources. The only thing we did to make it a true competition in the MCM is that we don't allow them to use people. They can use any and all inanimate resources: they can use libraries, computer programs, anything they want, as long as they don't go to some other professional and say, "How do you do this?" That's the only thing that's disallowed in the program. In fact, people have different skills, so that kind of interaction is the absolute best. It's the way people should learn; it's the way they are asked to act in the real world.

I should also point out that the "teachers, too" part. You're right in making the point about teachers having a terrible life: it's true. On the other hand, presumably, many of the teachers into the field because they care about and like mathematics and, at some point, they found someone responding. Everytime I've ever talked to groups in high school--elementary school teachers for that matter--the same kinds of examples are fun, and students and teachers remember and enjoy them. We've got to treat the teachers the same way we would treat the bright students--or all students, for that matter. Like them, respect them, and play a little bit. It would be nice if we could all effect the salary scale and the work

load and all of that, but given that we don't have that power at least we can give them some serious enjoyment. That's basically the only approach.

The last thing I would say is that I think the issue of applied versus pure mathematics is over. It's all one subject. Even at the research level now, nobody can tell the difference anymore. People are still fighting it because there's some good old jokes you want to be able to tell, about how you can tell a pure mathematician from an applied mathematician. The mix is so thorough, it no longer makes sense to separate the two. It was fun, and it was useful, but it isn't true any more; it's not a real debate anymore. And all of these things I think fit in different fields. We can look at the subject of mathematics in a lot of different ways.